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## **The Analysis and Impact of Remanufacturing Industry Practices**

**Ibrahim GURLER <sup>1</sup>**

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### ***Abstract***

*Remanufacturing is a process of bringing used products to “like-new” functional state with warranty to match. Remanufacturing industry is rapidly emerging as an important form of waste prevention and environmentally conscious manufacturing. Products are remanufactured through a series of industrial processes including disassembly, cleaning, inspection, reconditioning, reassembly and testing.*

*The objective of this paper is to review the literature available and examine the terminology surrounding remanufacture, and establish definitions for the various processes such as recycling, refurbishing and reconditioning that are used synonymously. Secondly, via a review of industrial practice, the key business drivers faced by the remanufacturing industry are presented.*

**Keywords:** *Remanufacture, Remanufacturing Industry, Environmental Impact, End-of-Life*

**JEL Codes:** *M11, L60, Q50*

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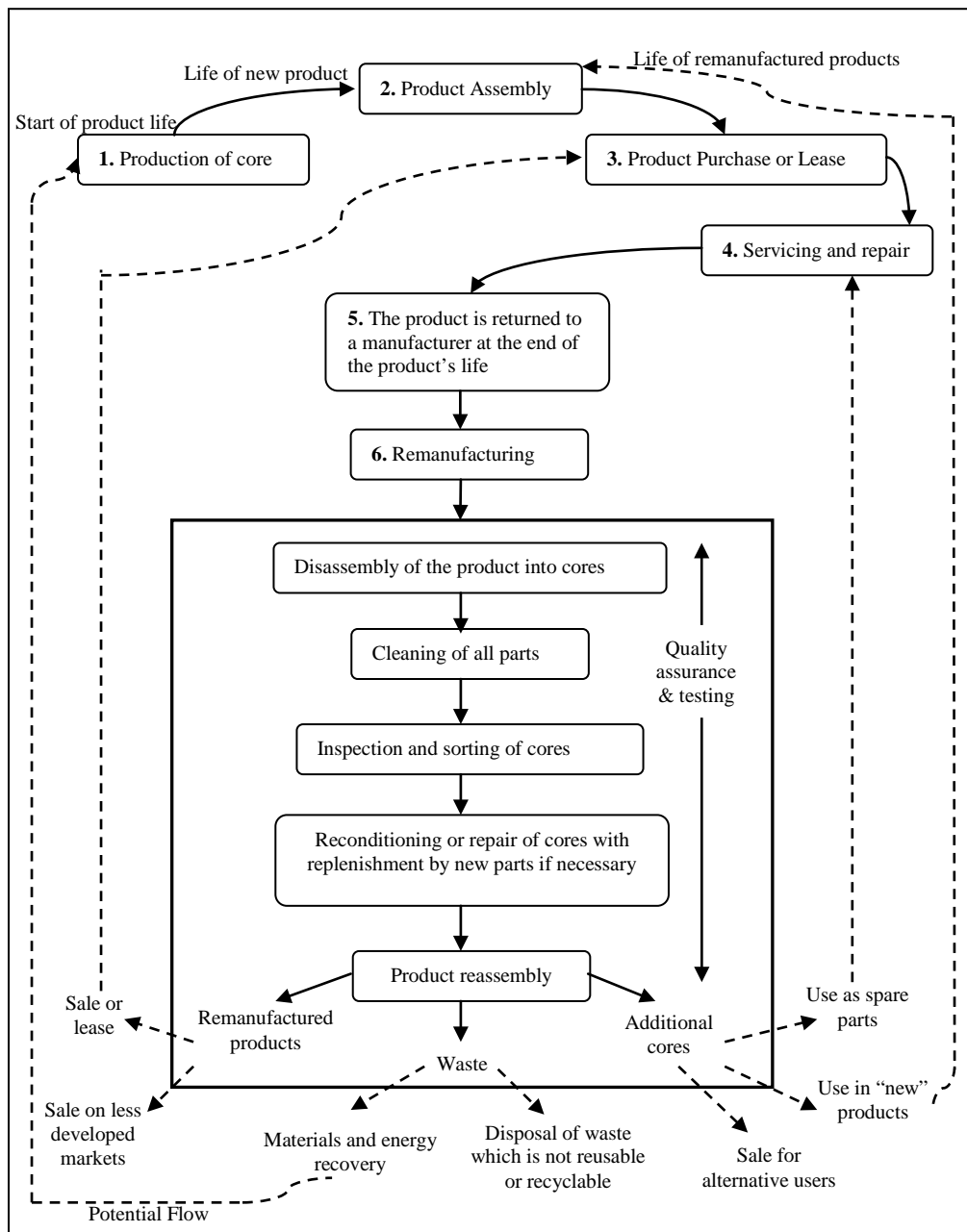
### **1. Introduction**

The remanufacturing industry is a large and economically important industry that includes many market sectors and provides significant societal and environmental benefits. The aim of remanufacturing is to reprocess used products in such a manner that the quality of the products is as good or better than new in terms of appearance, reliability and performance.

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<sup>1</sup> Assist. Prof. Dr. Engineering and Architecture Faculty, Gediz University, Turkey, [ibrahim.gurler@gediz.edu.tr](mailto:ibrahim.gurler@gediz.edu.tr)

**Figure-1: A Generic Remanufacturing Process**



Source: Kerr and Chris, 2001:76

The remanufacturing industry has been described as an “invisible industry”, “hidden giant” and “important though little understood industry” (Parkinson, 2003:243). Remanufacturing is a process of bringing used products to “like-new” functional state with warranty to match. Remanufacturing typically begins with the arrival of a used product (called a core) at the remanufacturer, where it passes through a series of industrial stages including disassembly, cleaning, part remanufacture and replacing of unremanufacturable parts, reassembly and testing to produce the remanufactured product. The order in which these activities, shown in Fig. 1, are undertaken may differ between different product types. Remanufactured products typically have the same or similar performance characteristics and quality standards as new units.

**Table-1: Remanufacturing Process**

<b>Disassembly</b>	The requirement for remanufacturing disassembly is that it be non-destructive. The remanufacturers showed great ingenuity in developing processes for disassembling crimped and rivet fastenings in a manner that caused the least destruction to components. Disassembly equipment includes electric and pneumatic power tools and general workshop tools, especially hammers, mallets and drifts, wrenches, jigs and holding fixtures, bearing presses and drills
<b>Cleaning</b>	Effective cleaning requires that all contamination be removed and involves degreasing, derusting and the removal of surface coatings such as paint. Many methods are available such as cleaning in petrol, hot water jet or steam cleaning, chemical detergent spraying or chemical purifying baths, ultrasonic cleaning chambers, sand/bead blasting, steel brushing and baking ovens.
<b>Inspection and sorting</b>	As part of the remanufacturing processes, the components making up an assembly have to be sorted into their unique groups for further processing. Inspection is an important stage that seeks to assess the reusability of a part and whether it can be reconditioned. The first thing is to establish objective criteria to determine the condition of a component. Once these criteria are established, an effective means of assessing the criteria must be developed. If it is not possible to achieve this cost effectively, the criteria should be revisited. Visual inspection is widely used, along with non-destructive testing (NDT) techniques such as dye penetrant, magnetic particle, eddy current and ultrasonic methods
<b>Reconditioning</b>	Reconditioning processes include milling, turning, grinding, material deposition, heat treatment, welding, powder coating, chroming and spray painting. An example of this would be the regrinding of crankshafts and the fitment of oversize bearings

<b>Reassembly</b>	Reassembly usually takes place on small batch assembly lines, using the same power tools and fixtures that were employed for the assembly of the newly manufactured product. Because production runs are likely to be lower in remanufacturing, it will be harder to justify the use of automation, as the cost could not be amortized over as many products
<b>Testing</b>	Testing is likely to be similar to that used on newly manufactured products. Remanufacturers typically use 100 per cent inspection testing of finished goods, which may be higher than a new manufacturer who may sample a percentage of the products for testing

Source: Adopted fromf Parkinson and Thompson: 2003:252

In recent years, sustainable manufacturing has become important all over the world. Manufacturers have begun to realise the need for the responsible use and management of resources in the life cycle of a manufactured product, especially the planning for product retirement. The common end-of-life options are reuse, remanufacture, recycle, landfill, and incineration. Except for landfill and incineration, components of economic value destined for reuse, remanufacture, or recycling have first to be extracted from the product. It is therefore necessary to determine the optimal stage of disassembly, when all economically valuable components are retrieved.

The types of products being remanufactured vary, generally falling into two classes: capital goods and consumer durable goods. Capital goods can be anything from complex military weapon systems to manufacturing, mining, and agricultural equipment to vending machines. Capital goods remanufacturing is also the more mature of the two types, having existed in one form or another for much of the twentieth century. In the case of consumer durable goods, process costs can often exceed the price of a new product, which has limited their use in many industries. Large-scale remanufacturing of products outside the domain of capital goods is still in its infancy, and time will tell how this opportunity will yet be exploited. There are, however, some prominent examples of successful remanufacturing of consumer durable goods—automotive parts, computers, laser toner cartridges, copiers, medical equipment, office furniture, aviation equipment, tires and single-use cameras are a few (Giuntini 2003:42).

The key remanufacturing drivers are environmental concerns (the need to reduce waste during the material extraction and manufacturing processes and throughout the remainder of the product life cycle), legislation (international agreement to reduce the environmental impact of products and manufacturing processes) and economics, because remanufacture is often a quality and cost-effective option (Ijomah, 2007:3).

From an ecological perspective, it is desirable to considerably reduce the waste generated in the material extraction and processing phase of manufacture, as well as to reduce the energy consumption used during the manufacturing process. Legislation regarding the reclamation of manufactured products has been driven by the public's awareness of ecological concerns and energy consumption. As with any business venture, economics become a factor which drives decisions. Remanufacturing offers more economic benefits than material recycling, or other reclamation processes, in general. Where very little investment is often required to restore an assembly to like-new condition, remanufactured parts cost significantly less than new products - allowing for the business to realize greater profits than if the constituent materials of the product had been recycled (Amezquita, 1995:272)

As world population increases, more resources will be consumed to satisfy demand, leading to more waste generated. If common appliances such as washing machines, refrigerators, automotive plastics, and other consumer products are not designed for recycling, the embedded stock of potentially unrecoverable materials is very large (Lee,2001:148). Designing products for sustainable development has become a pressing concern. One way to achieve this is to undertake a life cycle assessment (LCA) for a product. LCA seeks to minimise the environmental burden arising from the manufacture, use, and eventual disposal of products. Design engineers, in particular, ought to consciously plan for product retirement. For example, should the product be discarded in a landfill, reused, or recycled in whole or in part?

## **2. Terminology about Remanufacturing**

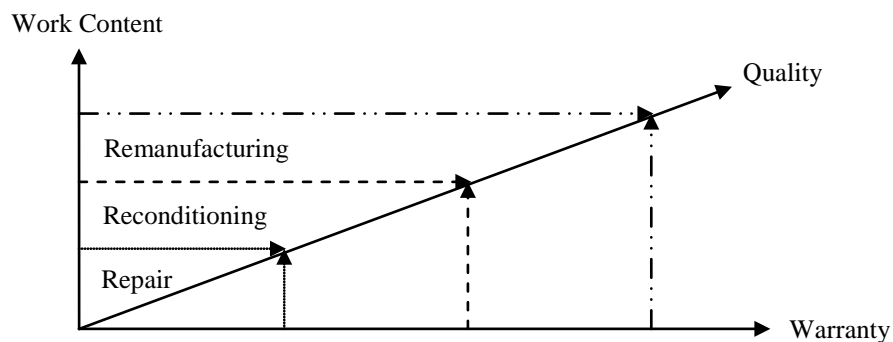
### **2.1. *Repairing, Reconditioning, Remanufacturing and Recycling Terms***

The terms repairing, reconditioning remanufacturing and recycling are often used synonymously and can be defined as following (King, 2005):

**Repairing** is simply the correction of specified faults in a product. Generally, the quality of repaired products is inferior to those of remanufactured and reconditioned alternatives. When repaired products have warranties, they are less than those of newly manufactured equivalents. Also, the warranty may not cover the whole product but only the replaced component.

**Reconditioning** involves less work content than remanufacturing, but more than repairing. This is because reconditioning usually requires the rebuilding of major components to a working condition that is generally expected to be inferior to that of the original model (King, 2005). All major components that have failed or that are on the point of failure will be rebuilt or replaced, even where the customer has not reported or noticed faults in those components. The fact that a reconditioned product is clearly not new (and thus not offering the latest functionality or aesthetic styling of new product) means that it has the same market acceptance issues as products that have been repaired.

**Figure-2:** A hierarchy of secondary market production process



Source: (Ijomah, McMahon, Hammond, and Newman, 2007:3)

**Remanufacturing** is the only process where used products are brought at least to original equipment manufacturer (OEM) performance specification from the customer's perspective and, at the same time, are given warranties that are equal to those of equivalent new products the reasoning here being that if a remanufactured product has quality equal to that of a new equivalent then its

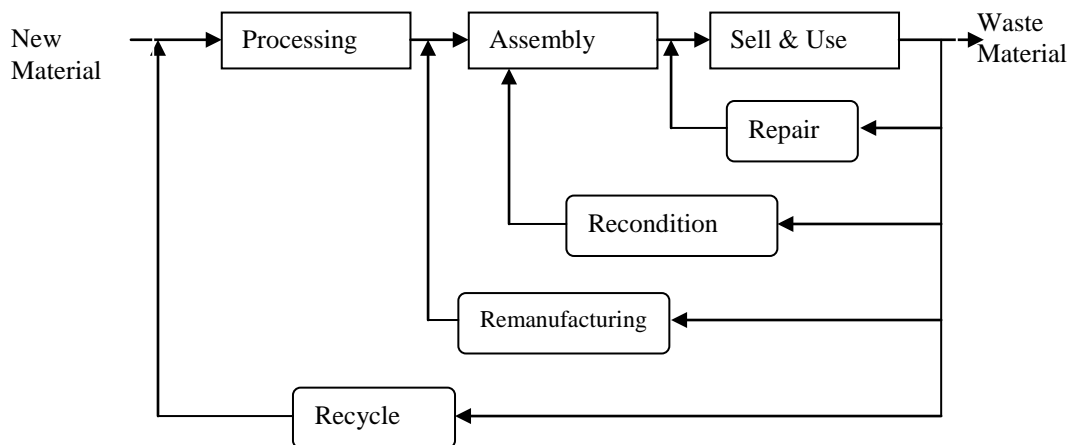
warranty must also be the same. Remanufacturing requires the total dismantling of the product and the restoration and replacement of its components.

**Reuse** is using good components from retired assemblies. It means continuing to use a product, rather than destroying it (as is the case in recycling).

**Recycling** is “the series of activities by which discarded materials are collected, sorted, processed, and used in the production of new products”.

Remanufacturing typically involves a greater degree of work content than repair and reconditioning, so its products generally have superior quality. This is because remanufacturing requires the total dismantling of the product and the restoration and replacement of its components. Fig. 2 shows the three operations in a hierarchy based on the work content that they typically require, the performance that should be obtained from them and the value of the warranty that they normally carry.

**Figure-3:** Closed loop design through repair, remanufacturing or recycling



Source: King, Burgess, Ijomah, and McMahon, 2005

In order to achieve a step change in practice, designers need to consider the entire “life-cycle” of a product from raw material extraction, through manufacturing, product use and final disposal. From doing this, a key concept to true sustainability is identified as ‘closed loop design’, where disposal streams are diverted to become new raw material / manufacturing streams. This is illustrated in Figure 1.

**Table-2:** Examples to illustrate definitions

Term	Examples
<b>Repair</b>	Replacing a broken cam belt in an engine
<b>Reconditioning</b>	Rechroming and grinding a hydraulic ram to the OEM specification
<b>Remanufacturing</b>	“Reconditioned engine” with a warranty equal to that of a new engine
<b>Reuse</b>	Buying a second-hand alternator from a scrap yard
<b>Recycling</b>	Shredding a plastic computer body into plastic pellets for injection moulding

Source: Adopted from Parkinson and Thompson: 2003:250

## **2.2. Recoverable Manufacturing Systems**

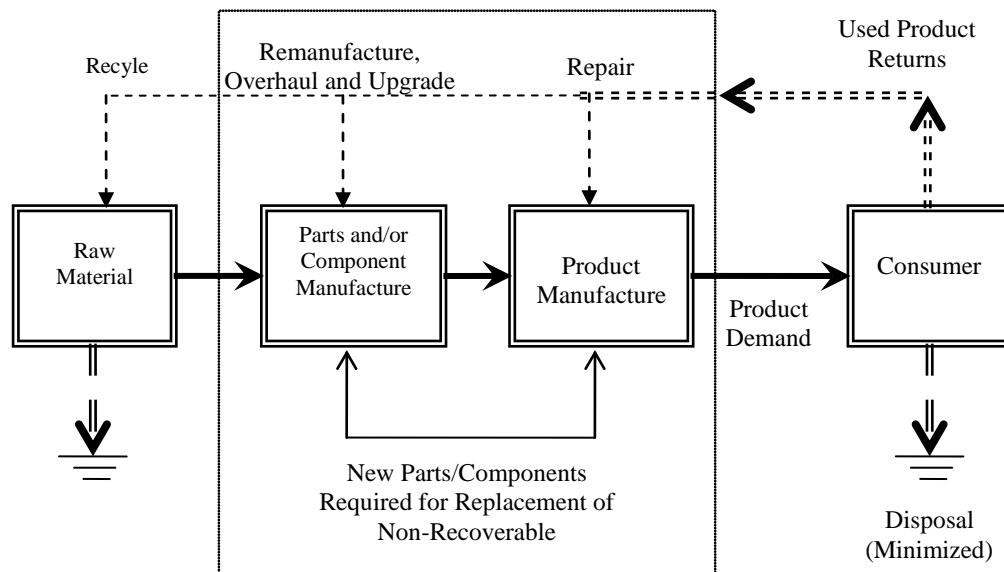
Remanufacturing is rapidly emerging as an important form of waste prevention and environmentally conscious manufacturing. Firms are discovering it to be a profitable approach while at the same time enhancing their image as environmentally responsible, for a wide range of products. There are numerous ways to minimize the environmental costs of manufacturing, but the prevention of waste products avoids many environmental costs before they occur. Waste prevention may take many forms, but one foundation of such a system is the recovery of materials used to manufacture and deliver products. A material recovery system; referred to as a recoverable product environment (see Fig. 3), includes strategies to increase product life consisting of: repair, remanufacturing (including technical upgrades), and finally recycling of products (V. Daniel, 1999:221).

A major part of the recoverable product environment is the recoverable manufacturing system that is designed to remanufacture products. Recoverable



manufacturing systems are faced with a greater degree of uncertainty and complexity than traditional manufacturing systems.

**Figure-4:** A recoverable product environment



Source: V. Daniel, 1999:222

### 2.3. End-of-Life Options for Manufactured Products

Products go out of use for essentially two reasons: functional obsolescence (they physically fail and need repair) or fashion obsolescence (they lose their appeal due to new products appearing in the market with different/additional features). Planned obsolescence is one way in which capitalist markets generate a demand for new sales (King, 2005).

When a product reaches the end of its useful life, it can be reused, remanufactured, recycled, incinerated in a landfill. The choice depends on whether the objective is to minimise environmental impact or deficit. It is preferable to recycling because it adds value to waste products by returning them to working order, whereas recycling simply reduces the used product to its raw material value.

The end-of-life options are defined as follows (Lee, 2001:149):

- A component is reused when it is used “as is” in the direct reuse or indirect reuse application. Examples of direct reuse: a refilled milk bottle; indirect reuse: a milk bottle used as a flower vase.
- Remanufacture involves retaining serviceable parts, refurbishing usable parts, or replacing reworked components from obsolete products.
- In high grade recycling a material is reprocessed into a form that can be used in the same or another “high” value product. For example, a car tire can be recycled as a remolded car tire or as a conveyor belt.
- In low grade recycling a material is reprocessed into a “low” value product, such as industrial grade rubber being reprocessed into a general grade rubber.
- A material is incinerated to produce heat and electricity.
- Waste products with no intrinsic value are dumped in landfills. This option is a poor environmental choice, and is limited to materials for which recycling and other end of life options are not technically feasible at the moment.
- Special handling is mandatory for all toxic or hazardous materials. Such materials cannot be processed by any of the six options mentioned earlier.

#### **2.4. Remanufacturing Economy**

Today, there are two major structural limitations precluding the expansion of remanufacturing activities. The existing infrastructure is not suitable for the return flow, and most products arriving at the end of the first useful life are not designed for remanufacturing. This situation may change. Manufacturers are

more conscious of their responsibility regarding product disposal, and are considering the adoption of Design for the Environment (DFE).

In addition, changes in legislation may require manufacturers (or importers) to take back the carcasses of end-of-life automobiles, electronic goods and other durable products for responsible disposal or, preferably, recovery. Consequently, when the industry adopts efficient reverse logistics and design for the environment, one may see a substantial increase in the remanufacturing activity, even if regulation fails to require it. Since remanufacturing affects the level of consumption of several inputs (raw materials, labour and energy), it will have significant impact on the economy, as it becomes a generalized practice (Ferrer , 2000:414)

The remanufacturing success stories available today (photocopiers, tire retreating) represent a tiny fraction of economic activity. Thus, we cannot be certain about their second-order effects. For example, intuition says that the reduction in the consumption of raw materials reduces the demand from utility suppliers and machinery manufacturers. Likewise, employment is reduced in the same industries. Nevertheless, it is hard to guess what direction total employment will take, since remanufacturing is also a labour-intensive activity. Original manufacturing (usually mass production) is much more able to capture economies of scale than remanufacturing. Due to heterogeneous inputs, the typical production rule adopts small lots. Also, disassembly is inherently more labour intensive, and less amenable to automation than is assembly (Ferrer , 2000:414).

Key questions are: what would happen if durable goods, such as automobiles, trucks, televisions and personal computers, were substantially remanufactured? How would it affect the demand for the traditional inputs in these industries? How would the massive presence of remanufactured goods affect the demand for raw materials? Some of the inputs, like energy and semi-finished goods, are expected to decline but labour utilization might increase.

Remanufacturing brings lower prices to the consumer, typically on the order of 30 to 40 percent less than similar new products. Society is arguably the greatest beneficiary of remanufacturing. As a material productivity initiative,

the process has an intrinsic societal benefit in that it reduces the volume of energy and natural resources required to produce the goods we value. Remanufactured products incur costs that are typically 40 to 65 percent less than those incurred in the delivery of new products. This is because most of the raw materials already exist in their final form and thus require only a fraction of the material processing required of new products. In terms of energy consumption, remanufacturing a product requires only about 15 percent of the energy used to make the product from scratch (Giuntini, 2003:44)

### *2.5. Design for Remanufacturing Guidelines*

Companies must design products for longevity and ease of recovery of their materials at end of life, and must consider the business potential of processing used products to harness the residual value in their components.

General design-for-recycling guidelines were formalized in the German engineering standard, VDI 2243 (Amezquita, 1995:275). This guideline contains directional criteria for the design of remanufacturable and recyclable products. Remanufacturable assemblies should be designed with special emphasis on the following:

- **Ease of disassembly:** Where disassembly cannot be bypassed, by making it easier, less time can be spent during this non value-added phase. Permanent fastening such as welding or crimping should not be used if the product is intended for remanufacture. Also, it is important that no part be damaged by the removal of another.
- **Ease of cleaning:** Parts which have seen use inevitably need to be cleaned. In order to design parts such that they may easily be cleaned, the designer must know what cleaning methods may be used, and design the parts such that the surfaces to be cleaned are accessible.
- **Ease of inspection:** As with disassembly, inspection is an important, yet a non-value-added phase. The time which must be spent on this phase should be minimized.

- **Ease of part replacement:** It is important that parts that wear are capable of being replaced easily, not just to minimize the time required to reassemble the product, but to prevent damage during part insertion.
- **Ease of reassembly:** As with the previous criteria, time spent on reassembly should be minimized. Where remanufactured product is assembled more than once, this is very important. Tolerances also relate to reassembly issues.
- **Reusable components:** As more parts in a product can be reused, it becomes more cost effective to remanufacture the product (especially if these parts are costly to replace).
- **Standardization:**
  - **Modular components:** By making designs modular, the assembly and disassembly times can be reduced which enhances remanufacturing.
  - **Fasteners:** By standardizing the fasteners to be used in parts, the number of different fasteners can be reduced, thus reducing the complexity of assembly and disassembly, as well as the material handling processes.
  - **Interfaces:** By standardizing the interfaces of components, a fewer of parts are needed to produce a large variety of similar products. This helps to build economies of scale which also improve remanufacturability.

### **3. Conclusion**

Remanufacturing is currently not without significant barriers. Reverse logistics, returning

end-of-life products to a small number of locations, can be the biggest cost involved in remanufacturing. A variety of approaches are used to receive the old product including new product discounts, free postal return and voluntary sector partnerships with retail groups. Key remanufacturing barriers include consumer acceptance, scarcity of remanufacturing tools and techniques and poor remanufacturability of many current products.

When end-of-life products arrive at a potential remanufacturing factory, a manufacturer needs to disassemble the product. This can be difficult and expensive and was found to be a fundamental barrier. A variety of approaches are used including part standardization, reversible assembly methods and modular/platform design. Once the products/parts have been disassembled, the manufacturer needs to find out what condition the products/parts are in. If the parts are suitable for remanufacture they may go to one location; otherwise they would be sent for recycling or landfill.

Remanufacturing can contribute greatly to the development of sustainable products. The reuse of components will reduce the energy required to process raw material and components and make less demand on the environment.

Remanufacturing is much more than the replacement of components. Its potential is to provide products that can be updated and enhanced by new technology and that can be developed in function throughout their life. Remanufacturing has the potential to improve customer satisfaction and economic performance through sustainable development.

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